Preliminary Account of a Telegraphic Determination of the Longitude of the Royal Observatory, Cape of Good Hope. By David Gill, LL.D., F.R.S., H.M. Astronomer at the Cape of Good Hope.

The longitude of the Royal Observatory, Cape of Good Hope, is the origin of longitudes for the British and American Transit of *Venus* Stations in South Africa and Madagascar. I have therefore thought it desirable to publish, as soon as possible, a brief account of the recent operations connecting the longitudes of Aden and the Cape, and to quote the approximate results obtained, in anticipation of the definitive results and more detailed account that will afterwards appear in the publications of the Observatory.

On Oct. 6, 1879, I addressed Sir George Airy, then Astronomer Royal, drawing his attention to the fact that about the end of the year the Cape would probably be in telegraphic communication with England, and asking whether advantage should not be taken of this circumstance to determine the longitude of the Cape of Good Hope as soon as possible. On Nov. 13 of the same year Sir George replied, "To mention the galvanic determination of the Cape of Good Hope Observatory is quite enough; the thing must be done as soon as may be."

After much correspondence and inquiry as to possibilities, I officially addressed the Secretary of the Admiralty on 1880, June 23, enclosing a general plan of the proposed operations, together with the necessary estimates of cost.

On 1880, Sept. 20, I took advantage of the kind invitation of Commodore (now Admiral) Sir F. Richards, K.C.B., to accompany him, as his guest, on board H.M.S. "Boadicea" to Port Elizabeth and Durban, partly to select sites of observation, but especially to ascertain whether signals could be exchanged directly between Aden and Durban without the intervention of an observer at Zanzibar. At Durban I made the necessary experiments, and found that signals sent from Aden, though quite useless for longitude purposes when received on the ordinary speaking galvanometers, were quite sharp and well marked when received on Thomson's air dead-beat* galvanometer. This fact I reported to the Admiralty by telegraph from Durban, and, on my return to the Cape, received official authority to proceed with the work. The necessary huts were soon made in Cape Town, but some unforeseen delays occurred in the despatch of the transit instruments and clocks from England, and it was not until 1881, March 2, that they reached the Cape.

* In the ordinary submarine galvanometer the mirror is suspended in water; in the air dead-beat the mirror is suspended in air. The mirror in the latter is nearly of the diameter of the cylinder in which it is hung, and the length of this cylinder is limited by glass plates. The mirror moves very freely at the first impulse, but the extension of the swing is checked by the passage of air round the edge of the mirror.

One of the transit instruments and a clock were mounted in a hut in the Observatory grounds without delay, and personal equation determinations were obtained on five nights. I was about to sail for Durban on March 18 when news was received of a breakdown of the land-lines from floods on the Transkei; difficulties also were presented by the discontinuation of the Mail Steamer Service between Durban and Delagoa Bay. I therefore postponed the commencement of actual operations for three months, and afterwards changed the original programme, relegating to Mr. Finlay, my chief assistant, the part of principal travelling observer; I had every confidence in his energy and skill, and my confidence has been amply justified by results. This modification of the original plan gave me more satisfactory control over the operation as a whole, and it enabled me at the same time to commence a series of heliometer researches on stellar parallax which must otherwise have been delayed for a year.

My general plan of operations was as follows:—The travelling observers were Mr. W. H. Finlay (F.), who successively occupied Durban, Aden, and the Cape; Mr. G. W. H. Maclear (M.), who observed first at the Cape, and afterwards at Durban; and Messrs. R. T. Pett (P.) and Isaac Freeman (I.), who remained at the Cape.

At the Cape (Observatory grounds), Durban, and Aden, there were erected three similar wooden huts, each containing a powerful portable transit instrument (3 inches aperture), a clock by Dent, and the necessary apparatus for sending and receiving signals.

The clock at Durban (the middle station) was regulated to mean time, the clocks at Aden and the Cape were regulated to sidereal time. At the Cape F. and M. observed exclusively with the 3-inch transit, P. and I. with the Transit Circle. The Observatory hut-clock and Observatory transit-clock were compared by coincident beats (through the intervention of mean time chronometers) by the observers before and after each time-determination.

Since Mr. Finlay observed both at Aden and the Cape, whilst Mr. Maclear remained at Durban, the sum of the longitudes Aden-Durban, and Durban-Cape Town, would be free from personal equation *if the personal equation of Finlay and Maclear remained constant during the operation, and if the personal equation of both observers was the same for land-line and for cable signals.*

But it would have been very unsafe to make any such assumption, for the operation was necessarily a very protracted one, the observers had long sea voyages intervening between the personal equation determinations and the actual observations, as well as great changes of climate and (as it proved) of bodily health. In fact, in such operations, the accidental error is a very small matter in comparison with the *possibility* of large systematic error due to change in the personal equation of the observers.

It was therefore essential to have some control on the constancy of the habit of observation of each of the travelling observers, and this I obtained by comparing the personal equation of F. and M. with that of $\frac{P.+I.}{2}$ both before and after the expedition.

That $\frac{P.+I.}{2}$ may be accepted as a tolerably uniform standard there was good *à priori* reason to believe. Both gentlemen were experienced observers, and had observed steadily and exclusively with the same instrument for the past eight years and twenty years respectively.

The following are the results of the different series of observations that have been made, under my direction, to determine their relative personal equation.

	No. of Stars.	P.−I.
		s
In 1879, Stars N.P.D. 75° to 105°	160	+0·178
,, 105 to 120	206	+0·229
Mean		+0·204

			Probable Error.
			s
1881, Apr. 9–June 27, Longitude Time Stars	10 nights	+0·229	±·009
Aug. 18–Sept. 19, ,,	7 ,,	+0·207	±·009
Dec. 23–1882, Feb. 17 ,,	8 ,,	+0·233	±·021

The remarkable constancy of these relative results may be accepted as proof of the probable constancy of the absolute personal equation of both observers.

From a discussion of the numerous observations for personal equation made before and after the expedition the following are the results obtained:

Before the Expedition.		After the Expedition.	
F.	+0·150	F.	+0·110
M.	+0·007	M.	+0·047
P.	+0·032	P.	+0·034
I.	−0·189	I.	−0·191
$\frac{P.+I.}{2}$	−0·079	$\frac{P.+I.}{2}$	−0·079

where F.+M.+P.+I.=0.

The personal equation of each observer both in sending and receiving land-line signals was also determined, by numerous trials, before and after the operation; these personalities resulted in quantities not exceeding $0^s{\cdot}01$, and are for the present neglected. The details will be given with a complete account of the operation.

To compare the personal equations of F. and M. in observing galvanometer signals, I arranged the following plan, which was

well carried out. I instructed F. to leave his clock at Aden, and to train a member of the telegraph staff there in the art of sending time signals. This duty was cordially undertaken by Mr. A. W. Prosser, of the telegraph staff there, and he acquired great skill in sending signals with uniformity and precision.

F. brought with him the Thomson dead-beat galvanometer which he had used at Aden, and mounted it in the hut at Durban, where the galvanometer used by M. was also mounted. Both galvanometers were then put in the Aden circuit, and signals sent by Mr. Prosser at Aden were observed by F. and M. at Durban, *each observer using his own galvanometer, but recording the same signal at the same place by the beats of the same clock.*

Any difference in the recorded times was therefore due either to personal equation or to a different degree of sensibility in the two galvanometers.

For longitude purposes it was not necessary to separate the observer's personality from the difference of the instruments, and therefore no observations were made with an exchange of galvanometers.

The following are the results of these experiments :—

Mean of 95 coincidences observed on 10 different days show that Finlay observed earlier than Maclear by $0^{s}\cdot261$.

And 1,820 differences (not coincidences) gave $0^{s}\cdot263$.

The experiments were made with the galvanometer of F. alternately first and last on the line.

If we separate these cases we have

Finlay's galvanometer first on line,	47 coincidences	$= 0^{s}\cdot267 \pm {}^{s}\cdot017$
Maclear's ,,	,,	$= 0\cdot255 \pm \cdot016$
	Mean	$0\cdot261$

That is, the clock times of submarine signals observed by Maclear with the Durban galvanometer require the correction $-0^{s}\cdot261$ to reduce to Finlay's habit of observation with the galvanometers employed by him at Aden.

There is still a final correction for personal equation of some importance ; it is as follows :—

All the time-stars were purposely selected between Declination $+12°$ and $-29°$, so as to lie between the zeniths of Aden and Durban. At the Cape, where the determinations of personal equation were made, the time-stars all move from right to left (i.e. from left to right in the field of the transit), but at Aden they move from left to right (i.e. from right to left in the field of the transit).

In 1879, in the course of some special investigations on personal equation, I found, for all the Observatory assistants without exception, that the personal equation, in observing a zenith star, systematically differs according as the feet of the observer

are towards the north or the south* (i.e. according as the star appears to cross the field from right to left or from left to right).

By placing a reversing prism between the eye-piece and the observer's eye, it is possible to make any star appear to move from right to left or from left to right at pleasure. In this way Mr. Finlay's difference of personal equation for stars (really) moving from right to left from stars (really) moving from left to right was

Before the Longitude Expedition	from	31	stars	$+0^{s}\cdot06 \pm 0^{s}\cdot012$
After	,,	,,	21 ,,	$+0^{s}\cdot08 \pm 0^{s}\cdot010$

Mr. Finlay's observations at Aden therefore require the correction $+0^{s}\cdot07$ applied to his determination of "clock slow" to reduce to his habit of observation in the southern stations.

For the time determinations a list of 389 time-stars was prepared. These stars were all situated between Declination $+12°$ and $-29°$ for reasons above explained, and all, as far as possible, of 6th magnitude. From this list the observer can find a time-star for every three or four minutes of R.A., so that no opportunity for observing between clouds need be lost. A further list of 87 circumpolar southern stars were supplied to each observer. The places of all these time and polar stars have been determined with the Transit Circle (generally with a minimum of 6 observations each). The circumpolar list was printed and circulated for the benefit of Transit of *Venus* expeditions to the southern hemisphere. A time determination was defined as follows:—

1. Collimation by reversal on a collimator.
2. Level; 4 reversals.
3. Observe 4 time-stars; one pole star above, and one below, pole.
4. Level; 2 reversals.
5. Reverse Transit instrument.
6. Level; 2 reversals.
7. Observe 4 time-stars; one pole star above, and one below, pole.
8. Level; 2 reversals.

A complete determination of longitude was supposed to consist of such a time determination both before and after the exchange of signals at both ends, but it was found necessary to relax this condition because of the interruptions of cloudy

* These results were F. +·079
M. +·122
P. +·015
I. +·066

weather, which would have unduly prolonged the operation if this condition had invariably been insisted upon.

I have therefore accepted all the results in which there is a complete time determination at both ends within two or three hours of the exchange of signals; but no time determinations are accepted in which stars have not been observed in both positions of the transit.

The values of the levels were determined before and after the expedition.

All the observations have been made by *eye and ear* not only in the time determinations, but in sending and receiving signals. All signals have been given and observed by *coincidence*.

In order to obtain an additional control on the longitude of Durban, and thence on the personal equation of F. and M., I took advantage of a visit which Mr. Pett was about to make to Natal in July 1882. The Durban hut with its transit and clock were accordingly left *in situ*, in charge of the Government clerk of works.

Before and after his visit to Durban Mr. Pett determined his personal equation relative to Mr. Finlay, both observers using the three-inch Transits.

The results obtained were

	F.–P.
Before the departure of P.	+0·000
After the return of P. ...	+0·040
Mean	+0·020

After the application of all corrections for personal equation so derived, the following results were obtained:—

Cape Transit Circle West of Durban Hut.

Observers.	Date.	h m s
I. Finlay, at Durban Maclear at Cape	June 1881	0 50 12·148 on 4 days. ±·025*
II. Finlay at Durban Pett and Freeman at Cape with Transit Circle	June 1881	12·176 on 4 days. ±·018*
III. Maclear at Durban Pett and Freeman at Cape with Transit Circle	Aug. & Sept. 1881	12·199 on 3 days. ±·022*
IV. Maclear at Durban Finlay at Cape	Dec. 1881 & Jan. 1882	12·196 on 3 days. ±·017*

* These so-called "probable errors" are merely deduced in the usual way from the agreement of the separate results of each operation.

Observers.	Date.	h m s
V. Maclear at Durban Freeman and Pett at Cape with Transit Circle	Dec. 1881 & Jan. 1882	0 50 12·192 on 6 days. ±·030*
VI. Pett at Durban Finlay at Cape Both using 3 in. Transits	July 1882	12·152 on 2 days. ±·004*

In these six operations the personal equations have been applied as follows:—

I. and II. F. = +0·150 = His equation as determined before leaving the Cape.

IV. F. = +0·110 = His equation as determined after his return.

I. and III. M. = +0·007 = „ „ before leaving.

IV. and V. M. = +0·047 = „ „ after his return.

VI. F.−P. = +0·020 = Mean of their relative equation as determined before and after Mr. Pett's visit to Durban.

II. III. and V. $\frac{P.+I.}{2} = -0·079$ = Constant.

To obtain the most probable value of the difference of longitude Durban—Cape, it will be perhaps best to give equal weight to the observations of the most strictly separate determinations, viz.:—

Cape (*Transit Circle West*) *of Durban* (*Transit Hut*).

			h m s
Finlay at Durban,	I. and II.	=	0 50 12·162
Maclear „	III. IV. and V.	=	12·196
Pett „	VI.	=	12·152
		Mean	0 50 12·170

It will now be convenient to give the separate results for the difference of longitude Aden—Durban. They are as follows:—

Durban, West of Aden (*uncorrected*).

		h m s
VII.	Aug. 20	0 55 48·71
	23	48·59
	Sept. 2	48·43
	13	48·60
	18	48·32
	19	48·575
	22	48·45
	23	48·65
	26	48·53
	28	48·45
		0 55 48·531

* These so-called "probable errors" are merely deduced in the usual way from the agreement of the separate results of each operation.

We have besides these the following results of direct comparison with the Cape, Durban having no observations on these nights :—

Cape Transit Circle West of Aden.

		h m s	
VIII.	Aug. 26	1 46 0·69	Cape Observers, P. and I.
	27	0·53	„ „
	Sept. 3	0 75	„ P.

These results are without correction for personal equation.

In order to discuss the all-important question of the personal equation of Mr. Finlay at Aden, I adopt as definitive the above-found value of the longitude of the Cape west of Durban. Then for the mean of operations I. and II. we get for the seconds of the longitude in question $12^{s}\cdot162$, which would imply that at the time in question Finlay's adopted personal equation required the further correction $+\cdot008$, that is

$$\text{In June 1881} \qquad F. = +0^{s}\cdot158 \ldots \quad \ldots \quad (1)$$

From operation III. the seconds of the longitude are 12·199, which would imply that at the time in question Maclear's adopted equation required the correction $-0^{s}\cdot029$, that is—

$$\text{In Aug. and Sept. 1881} \qquad M. = -0^{s}\cdot022 \quad \ldots \quad (2)$$

The operations IV. and V., from their agreement with the result of operation III., appear to show the reality of the change of $+0^{s}\cdot040$ in Maclear's personal equation between September and December 1881, and that Maclear's personal equation for the latter period requires a correction of $-0^{s}\cdot024$, that is—

$$\text{In Dec. 1881, and Jan. 1882} \qquad M. = +0^{s}\cdot023 \ldots \quad (3)$$

When Mr. Finlay returned to Durban from Aden he compared personal equation with Mr. Maclear on four nights with the result—

$$\text{In Nov. 1881} \qquad F. - M. = +0^{s}\cdot208 \quad \ldots \quad (4)$$

If we suppose Mr. Maclear's habit of observation to have changed gradually between September and December, we cannot be far wrong in adopting from (2) and (3) —

$$\text{In Nov. 1881} \qquad M. = +0^{s}\cdot010, \text{ and hence from (4)}$$
$$\text{„} \qquad F. = +0^{s}\cdot198 \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

We have from (1) and (5)—

$$\text{In June 1881} \qquad F. = +0^{s}\cdot158$$
$$\text{Nov. „} \qquad F. = +0^{s}\cdot198$$

And I adopt the mean of these as the most probable value of Mr. Finlay's personal equation at Aden in August and September.

We have, therefore, for the personal equation of F. and M. during the exchange with Aden—

In Aug. and Sept. 1881	F. = +0ˢ·178	...	(6)
„	M. = −0ˢ·022		

The results of operation VII. will therefore require the following corrections:—

	Corresponding Correction to Difference of Longitude.
	s
Correction of −0ˢ·261 to Maclear's time of recording submarine signals	+0·131
Correction for Finlay's personal equation in determining time (6) (+0ˢ·178)	+0·178
Correction to same on account of reversal of direction of star's apparent movement in the northern hemisphere (+0ˢ·070)	+0·070
Correction for Maclear's personal equation in determining time (−0ˢ·022)	+0·022
	+0·401
Uncorrected result of operation VII. ...	0 55 48·531
Add Cape, West of Durban	0 50 12·170
Hence Cape, West of Aden	1 46 1·102

The three results of operation VIII. all require the first three corrections of No. VII. The results of August 26 and 27 require, besides, the correction

$$-\frac{P.-I.}{2} = +0^s\cdot079,$$

and the result of Sept. 3 requires the correction

$$-P. = -0^s\cdot033.$$

So corrected, the separate results become:—

Cape Transit Circle, West of Aden.

	h	m	s
Aug. 26	1	46	1·148
27			0·988
Sept. 3			1·096
Mean	1	46	1·077

It is almost needless to discuss the relative weight that should be given to these two closely accordant results, for it must

be remembered that the personal equation adopted for Maclear in operation VII. depends on exchanges with the Cape on only three nights.

Had Mr. Maclear's personal equation been supposed constant during his stay at Durban (which, in view of the probable errors of the separate determinations, is not an inadmissible supposition), and accepting $0^h\ 50^m\ 12^s{\cdot}170$ for the definitive difference of the longitudes of Durban and the Cape, we should have as the personal equation of Maclear—

$$M. = +0{\cdot}008 \text{ during his stay at Durban,}$$

and this would make the personal equation of Finlay—

In Nov. 1881	F. =	$+0^s{\cdot}200$	Mean $+0^s{\cdot}179$
and as before in June „	F. =	$+0^s{\cdot}158$	

The former results of operations VII. and VIII. would then require the corrections $-0^s{\cdot}029$ and $+0^s{\cdot}001$ respectively, and would become:—

Cape Transit Circle, West of Aden.

	h	m	s
By operation VII.	1	46	1·073
„ VIII.			1·078

It is obvious from these considerations that if we take the mean of the two solutions of operation VII. we adopt the mean of the almost equally probable hypotheses, and in consideration of the number of observations in operation VII., we may allow it double weight.

We have thus definitively—

	h	m	s	
From operation VII.	1	46	1·087	wt. 2
„ VIII.			1·078	wt. 1

whence—

Cape Transit Circle, West of Aden	1	46	1·084

Economic considerations prohibited the exchange of observers at Aden, and therefore the chief uncertainty of the final result must be the personal equation of the observer at Aden. The results of Mr. Finlay's personal equation, determined at Aden two months before and two months after the Aden observations, differ only $0^s{\cdot}04$, and I think it extremely improbable that his true personal equation at Aden differed by this amount from the adopted mean.

The case will probably be met by assigning to the whole operation a probable error of $\pm 0^s{\cdot}03$. Beside such an error the accidental errors of the operation are comparatively insignificant —their rigid computation is therefore unnecessary.

The site of the station at Aden is the same as that occupied by the Royal Engineers of the G. T. Survey of India, in their connection of the Longitude of Bombay with that of Sir George Airy's Transit of *Venus* Station (Hunter's Station) at Suez. I accept the result of General Walker as quoted in Annual Report of the G. T. Survey of India, 1876–77, viz.—

	h	m	s
Aden, East of Hunter's Station, Suez ...	0	49	42·656

The Longitude of Hunter's Station, Suez, depends on the operations described in the "Account of the Observations of the Transit of *Venus*," British observations of 1874, edited by Sir Geo. B. Airy, of which the result is given on page 346 of that work, viz.—

	h	m	s
Hunter's Station, East of Greenwich ...	2	10	13·17

Combining these results, we have—

	h	m	s
Hunter's Station, East of Greenwich ...	2	10	13·17
Aden, East of Hunter's Station	0	49	42·656
Aden, East of Greenwich	2	59	55·826
Cape Transit Circle, West of Aden, as determined in the present paper	1	46	1·084
Cape Transit Circle, East of Greenwich ...	1	13	54·742

It is not probable that the result for "Cape, West of Aden" will be sensibly changed by further discussion, or by the small corrections that may yet be due to improved places of some of the Northern Circumpolar Stars. The absolute value "Cape, East of Greenwich" may yet be sensibly modified when the definitive discussions of the Longitude operation in connection with Lord Lindsay's and the German Expedition to Mauritius have been published, but I do not think that the difference will be of consequence for Transit of *Venus* purposes.

The Secondary Longitudes on the East Coast of Africa, which form the subject of a separate paper by Mr. Finlay, have been undertaken as a labour of love, and carried out by him with much spirit and energy.

I cannot conclude this paper without an expression of my grateful thanks:—

(1) To Sir James Anderson, who most generously placed the submarine cables between Aden and Durban entirely at my disposal for this work.

(2) To James Sivewright, Esq., C.M.G., General Manager of Telegraphs at the Cape, for not only placing the whole South African system of land-lines at my

disposal, but also for making all the necessary arrangements, and supplying all necessary aid. Also for the exact execution of this work to Mr. J. P. Edwards, his able and active assistant.

(3) To H. Carlisle, Esq., and C. Stacey, Esq., the superintendents at Durban and Aden, not only for the efficient aid they rendered, but for their kindly hospitality to all engaged in the work.

(4) To H. McEwen and A. W. Prosser, Esq., members of the telegraph staff at Durban and Aden respectively, for the active share which they took in the work, for the intelligent interest which they displayed, and for the great enhancement of its value which resulted from their labours of love.

Elliptic Elements of Comet b, 1882. By John Tatlock, Jun.

(Communicated by Prof. T. H. Safford.)

The present orbit is communicated as of possible interest, in comparison with the orbits of Dr. Kreutz and Prof. Frisby, with regard to the indications of the motion of the comet after it had passed perihelion. It was arranged for computation before Dr. Kreutz's elements, contained in No. 2482 of the *Astron. Nach.*, came to hand, as the copy of that number intended for this institution was lost in the "Cimbria." Had I seen his orbit sooner I should have made some changes in the dates of the places from which my orbit was computed. As it is, however, the date of my third place is 76 days later than the date of Dr. Kreutz's third place, and 66 days later than that of Prof. Frisby's. This fact will probably account for some of the discrepancies between the orbits of the above-named gentlemen and my own.

The elements are as follows, the computation being made by Gauss' method, as given in the *Theoria Motus*:—

Comet b, 1882.

T	=	Sept. 17·14302	
Log. q	=	7·9164079	
ω	=	70° 2′ 23·16″	Mean Equinox 1882·0
Ω	=	346 18 30·45	
i	=	142 3 28·22	
ϕ	=	89 20 18·35	
a	=	123·75	
e	=	·9999332	
P	=	1376·6 years.	